

identified some modifications to the Technical Standards proposed in the *NPRM*. These proposed changes and the rationale for them are discussed below.⁹

Allowed Vehicular Power

38. The *NPRM* proposes that vehicular radars be allowed an in-band power of 30 microwatts/square centimeter, measured at a distance of 3 meters. GM agrees that this proposed power, which equates to an EIRP (Equivalent Isotropic Radiated Power) of 34 Watts is reasonable as the nominal power for a vehicular radar at 76 GHz. However, the regulatory limit needs to be about 3 dB higher at 76 GHz and should be adjusted upward at the higher frequencies to compensate for the inherent losses due to the increase in frequency. We also believe it is necessary to limit the peak power to the values listed in the table below.

39. Thus, GM supports the AAMA recommendations for maximum average and peak power, which are as follows:

Band (GHz)	Avg Pwr uW/cm ² @3m	Peak Pwr uW/cm ² @3m
76	60	300
94	110	300
152	220	600

⁹ While GM supports the proposed vehicular radar allocation at 47 GHz, neither GM nor its subsidiaries have any intention of implementing a forward vehicular radar device in this band. Hence, GM is unable to discuss the particular technical rules that should be applicable to that band. Thus, all of our comments in this section on the technical rules, apply only to the 76, 94, and 152 GHz bands. (As discussed earlier, GM supports the AAMA recommendation to substitute the 152 GHz band for the 139 GHz band proposed in the *NPRM*.)

The 60 uW/cm^2 @ 3 m average power for the 76 GHz band is 3 dB above the anticipated HEM design power, which is also the limit proposed in the *NPRM*. Our rationale for recommending the 3 dB margin between nominal and maximum allowed is as follows. Normal production variation suggests a repeatability of ± 1 dB each for transmitter power and antenna gain. Combined with a ± 1 dB tolerance on the measurement, this results in a possible variation of ± 3 dB. Trying to match high power transmitters with low gain antennas in a production environment is cost prohibitive, as is trying to adjust the transmitter output on a unit to unit basis. Thus, GM is forced to design units with powers at least 3 dB below the allowed FCC limit. Without an increase in allowed power at 76 GHz, HEM would be forced to reduce range to an unacceptable value.

40. For a fixed beamwidth, i.e., a fixed antenna gain, received power decreases as the square of the increase in frequency. Thus, GM believes it is appropriate to increase allowed power at the higher frequency vehicular radar bands. The AAMA proposal essentially compensates for this decrease in received power as frequency increases.

Restrictions on Side Lobe Power

41. In ¶21, the *NPRM* text proposes to limit peak power density outside the main lobe to 200 nanowatts/square centimeter (we assume at 3 meters). This is 21.8 dB below the allowed power in the peak lobe (30 uW/cm^2 @ 3m). GM

notes, however, that the proposed language for new section 15.253 in Appendix B of the *NPRM* does not include this restriction. GM agrees that there is no need for a special restriction on the side lobe power of vehicular radars. If the Commission still feels some restriction is needed, then the limit should be modified to require a suppression of 15 dB for any antenna side lobe.

42. Even in the absence of an explicit FCC regulation on side lobe performance, vehicular radar manufacturers will limit radiated side lobe power. This is because good side lobe suppression is crucial to limiting false responses due to out-of-lane vehicles and roadside clutter. Thus, GM feels there is no particular need for an FCC mandate in this area.

43. The proposed requirement in the *NPRM* text of 21.8 dB is overly demanding and will unnecessarily increase the cost of vehicular radars. Practical systems require about 35 dB of total side lobe suppression, which includes the effect of both the transmit and receive antennas. Assuming equal antenna performance, a single antenna would require a 17.5 dB side lobe. This is consistent with typical antenna designs being considered for this task which achieve performance on the order of 20 dB side lobe suppression with a manufacturing variability of about ± 2 dB. Thus, imposing a regulatory requirement in excess of 15 dB would

unnecessarily increase the cost of these devices without any corresponding increase in benefits.¹⁰

Out-of-Band Limits

44. The *NPRM* proposes to mandate that vehicular radar out-of-band emissions limited to 2 picowatts/square centimeter when measured at 3 meters over a 1 MHz resolution bandwidth.¹¹ This limit, which equates to an EIRP of 2.2 microwatts, requires an extraordinary 72 dB of suppression.¹² This is clearly more than is needed for efficient management of the spectrum, will impose unreasonable costs on American drivers, and will, in the real world, be very difficult to measure and verify. We believe that a far more appropriate standard is to require suppression of out-of-band emissions by 25 dB below the in-band power.

¹⁰ As noted above in the section on Allowed Vehicular Power, GM is recommending some increases in allowed power. Thus, the corresponding levels for allowed average side lobe power would be as follows:

76 GHz band	1.9 uW/cm ² @ 3m
94 GHz band	3.5 uW/cm ² @ 3m
152 GHz band	6.9 uW/cm ² @ 3m

¹¹ See proposed §§15.35(b) and 15.253(c)(2) in Appendix B of the *NPRM*.

¹² Note that if the Commission adopts the GM and AAMA proposal to allow higher powers, but did not increase the allowed out-of-band requirement, the suppression requirement would be even higher than 72 dB.

45. The high intrinsic losses in the millimeter wave region require than any system working over any but the shortest distances use highly directional transmit and receive antennas. This significantly limits the impact of any out-of-band emission from vehicular radars on other millimeter wave systems. The fact that other systems will be located off the highway system -- where vehicular radars will be operating -- further limits the impact of these out-of-band signals. The net result is that efficient management of the spectrum does not require the stringent out-of-band suppression requirements proposed in the *NPRM*.

46. Meeting the proposed out-of-band suppression requirement of 72 dB would mandate the use of waveguide filters in both the transmitter and receive lines. In addition to the high cost this would impose, the size of these filters would also produce problems since these units need to be placed on the front center of a vehicle -- a location already subject to severe size restrictions because of the need for aerodynamic shaping of the car, the radiator air flow considerations, and styling considerations. Since none of GM's design work has ever contemplated such onerous suppression requirements, we are unable to provide any precise size or cost estimates, but they would be substantial. GM sees no need to impose such an unnecessary burden on the American driving public.

47. The high out-of-band suppression requirements create two significant measurement problems. First is the sheer difficulty of measuring (over 1 MHz resolution BW and up to 200 GHz) emissions of only 2.2 uW EIRP. This requires a very significant investment in special purpose measurement equipment, far beyond what is needed in any regular millimeter wave testing laboratory. The second problem is the very high dynamic range that must be available. These out-of-band emissions are not created in isolation. They must be measured in the presence of the much stronger fundamental. The proposed 72 dB suppression requirement far exceeds the readily achievable dynamic range of test equipment.¹³ In specifying performance requirements, the FCC should not be distracted by one-of-a-kind test setups created with high budgets more typical of defense contracts than consumer electronics. Instead, the FCC's goal should

¹³ For example, a typical millimeter wave test setup with a spectrum analyzer requires the use of an external mixer which saturates at input levels of about -5 dBm. With good setups, noise floors are on the order of -50 dBm, giving a total dynamic range of 45 dB. Keeping in mind that some of this dynamic range must be used to keep the measured emission out of the noise floor, there is not much room for suppression requirements in excess of the GM proposed value of 25 dB. Measuring edge-of-band suppression requirements that exceed the dynamic range of your test equipment is particularly difficult, short of building special purpose filters to "suck out" the fundamental and leave the out-of-band emission to measurement. Not only is there the high cost of constructing these special purpose filters, but it is also necessary to carefully test and characterize the filter so its effect on the out-of-band emission is accurately known. While somewhat simpler, suppressing the fundamental, so that harmonic emissions can be measured, is still a complicated process that will add unnecessary cost to the test process.

be to create performance requirements that can be easily measured with normal millimeter test equipment affordable by industry (and the FCC). As discussed below, trying to measure for very low out-of-band emissions also adds substantially to the amount of expensive technical effort needed to demonstrate compliance with the rules.

48. For the reasons discussed above, GM feels that the FCC should modify the proposal in the *NPRM* and require that vehicular radar out-of-band emissions be 25 dB below the in-band power.

Measurement Procedures

49. The Commission can significantly reduce the costs of compliance and facilitate the early introduction of a wide variety of vehicular radar alternatives to the driving public by adopting its traditional measurement procedures to accommodate the characteristics of millimeter waves. In particular, GM recommends that the FCC in its *Report and Order* explicitly (1) approve of using separate transmitter measurements and antenna data when that is practical and (2) limit required testing to the specific frequencies where radiated measurements can be expected.

50. In cases where it is possible to directly connect the transmitter and antennas to test equipment, allowing applicants to do so will significantly decrease the cost of measurements while allowing an increase in accuracy over automatically mandating radiated measurements. Direct

transmitter measurements are significantly easier to accomplish than radiated measurements. Almost all the Commission's rules for licensed radio services are based on transmitter measurements. While, in most cases, radiated measurements of antenna gain across frequency will still be needed, the ability to do this separately will still simplify the process. Power levels can be adjusted for maximum ease and accuracy in measurements. This is particularly critical when trying to measure harmonics and side lobes, since in normal device operation the radiated level of these signals is so low. Explicit acknowledgement by the Commission in the final decision of the appropriateness of using this approach would remove ambiguity.

51. Based on its experience, the FCC has always required applicants to carefully search for spurious signals from RF devices from the lowest RF frequency generated up to the specified upper limit. This is clearly appropriate for lower frequency devices since there can be complex interactions between clocks, oscillators, and other RF signals. Further, this is not an onerous process with the current state of automation in testing facilities. Many test ranges have equipment that automatically scans a device under test from 30 MHz to 1 GHz in one automated procedure. However, complete scans of the millimeter wave frequencies (i.e. 40-200 GHz as specified in the *NPRM*) are neither

necessary nor easy to achieve, particularly at the very low spurious levels that the *NPRM* proposes.

52. When the intended radiated signal is in the VHF or UHF range, signal processing circuits at VHF frequencies can interact with the RF generating circuit to create spurs that are significantly removed (as a percentage of the fundamental) from the intended signal. In contrast, any interactions from signal processing circuits, etc., with the millimeter wave generating circuits in a millimeter device will not be significantly removed from the intended signal. Thus, measurements of a millimeter wave device can be based only on the frequencies in the millimeter wave generating circuits.

53. As an example, if a 76 GHz vehicular radar directly generates its signal at 76 GHz (as opposed to generating it at 38 GHz and then doubling it), there are only two regions above 40 GHz that need to be examined for spurious signals. First is the band edge at 76.0 & 77.0 GHz and second is the second harmonic of 152 GHz. FCC measurement procedures, however, mandate that all the frequencies between 40 and 200 GHz be carefully tested. Actually performing these unneeded tests takes substantial time, since test equipment for millimeter wave frequencies is nowhere near as automated as it is at lower

frequencies.¹⁴ Note, that the testing time required is very much a function of the spurious limit. If the Commission were to actually retain the *NPRM*'s proposed spurious level of 2 picowatts/square centimeter @ 3 meters (2.2 uW EIRP), then testing these unneeded frequencies would be an extremely serious burden, since a great deal of time would be needed by highly skilled technicians and engineers to clearly establish that noise signals, mixer beats, etc., were artifacts of the measurement process and not actual emissions from the device under test.

RF Exposure Considerations

54. For obvious reasons, the Commission takes its responsibilities under the National Environmental Policy Act of 1969 to evaluate the potential impact of RF exposure on humans very seriously.¹⁵ As noted in the *NPRM*, the Commission has an outstanding Rule Making to evaluate the issue of updating its use of ANSI/IEEE C95.1-1982 standard on RF exposure with that standard's replacement ANSI/IEEE C95.1-1992.¹⁶ GM assumes that RF exposure concerns

¹⁴ Note that there is an asymmetrical burden here. The FCC in performing verification test can use good engineering judgment and only test the two locations needed, whereas the applicant is obligated to carefully (and unnecessarily) test the entire band.

¹⁵ National Environmental Policy Act of 1969, 42 U.S.C. §4321, et. seq.

¹⁶ See *Notice of Proposed Rule Making*, ET Docket No. 93-62. 8 FCC Rcd 2849 (1993). The FCC rules [§1.1307(b)] currently specify the use of American National Standard ANSI/IEEE C95.1-1982 "Safety Levels with Respect to Human Exposure to

underlay the *NPRM's* proposal to mandate that maximum vehicular radar emissions be reduced by 22 dB when the vehicle is moving below 1 kilometer/hour [proposed §15.253(c)(1)]. While GM shares the Commission's concerns about RF exposure, a careful review has shown that this proposal is unnecessarily restrictive and, as currently written, difficult to verify.

55. Before setting forth GM's proposed alternative, it seems useful to set forth some basic analysis of the RF exposure situation with respect to vehicular radars. Using the powers GM and AAMA are proposing, it is possible to set forth some "stand-off" distances (from the radome on front of the vehicle) at which it is clear that any human exposure meets the (more conservative) ANSI/IEEE exposure criteria. The other computation is the (more conservative) averaging time. By band the results are as follows:¹⁷

Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz" for determining if an Environmental Assessment is required due to RF exposure. IN Docket 93-62, the Commission is exploring whether the updated version of this standard, ANSI/IEEE C95.1-1992 "Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz," should be used.

¹⁷ To calculate the following table the more restrictive power limit, 5 mW/cm² in the 1982 standard was used and the averaging times in the 1992 standard was used. (Note that at these frequencies there is no difference between controlled and uncontrolled environments in the 1992 version.) One caveat is that the standoff distances were computed using a far field relationship, $S = \text{EIRP}/4\pi R^2$. Since the calculated standoff distances are in the near field of most devices, actual near field measurements may vary slightly from the calculated value. It is highly unlikely that the actual measured standoff distance will

Band (GHz)	Proposed Avg. Power (uW/cm ² @3m)	Standoff Distance (feet)	Averaging Time (seconds)
76	60	1	51
96	110	1.5	39
152	220	2	22

These standoff values are actually conservative because they were calculated assuming that the whole body would be exposed to the power density found directly in front of the radar at the standoff distance. This is clearly not the case, and the RF exposure standard allows for higher "partial body exposures."¹⁸

56. Based on the above calculations, GM proposes that the Commission modify its proposal so that the higher limits can be used whenever the vehicle is in a drive gear (rather than moving at 1 km/hr or higher). Our motive for wanting this change is that there are some circumstances where it is desirable to operate a vehicular radar when the vehicle is completely stopped. First, further implementations will want to provide some protection against situations such as "red light runners." To protect against such situations, the radar unit should be operating and tracking targets

significantly increase from those given below.

¹⁸

Since at 2 feet above the ground, the eyes and/or testes are not going to be exposed to the beam of a vehicular radar, the provisions of Section 4.4 Relaxation of Power Density Limits for Partial Body Exposures (in the 1992 version) are clearly applicable. In uncontrolled environments, the 1992 standard allows exposures of 20 mW/cm² for partial body exposure, twice the limit for whole body exposure (10 mW/cm²).

before the vehicle is in motion. Another future circumstance will be collision avoidance braking systems which will need to remain active until after the vehicle is brought to a complete halt.

57. Based on the calculations given in the above table, GM believes that vehicle radars radiating while the vehicle is in a drive gear will not result in human exposure to RF emissions in excess of the ANSI/IEEE standard (even if the Commission decides to retain the lower limit above 15 GHz found in the 1982 standard). People who linger closer than 2 feet in front of vehicles in drive gear face significantly higher safety risks than from RF exposure. About the only circumstances where people would be this close to the front center of a vehicle is in crossing streets in dense urban centers. Even the slowest pedestrians would cross the beamwidth of a vehicular radar well under the minimum 22 second averaging time.¹⁹

58. Even if one ignores the need for advanced vehicular radars to radiate at full power when the vehicle is stopped, the proposed wording creates some verification problems. It turns out, because of hysteresis problems, that building a speedometer that accurately determines when

¹⁹ While it is probably unnecessary, it is illustrative to put some numbers on the issue. A 6 degree beamwidth (3 dB) is as large as any practical vehicular radar system could use. At 2 ft away from the radome, the 3 dB beamwidth is only 2 1/2 inches in diameter. It would take someone crawling as slow as 7 inches per minute to remain in the beam for the full 22 second averaging time.

the vehicle speed crosses 1 kilometer per hour (km/hr) is complicated. Further, the speed sensor will be external to the radar sensor and decision making unit. This complicates the issue of how both the Commission and the applicant verify equipment performance. Simply requiring motion detection, rather than a specific speed threshold, will significantly simplify both implementation and verification of the requirement.

59. As discussed above, GM recommends that the criteria for allowing the full power be changed from vehicle speed at or above 1 km/hr to engaged in a drive gear. While this change is not necessary for the immediate generation of vehicular radars, it seems unproductive to introduce a rule that is unneeded to protect public safety (from RF exposure) and will ultimately need to be removed if the driving public is to fully enjoy the (traffic) safety benefits from the technology of vehicular radars. If the Commission is unable to make this change, then at least changing 1 km/hr to "in motion" will significantly ease the administrative burden on both the Commission and the applicants from this requirement.²⁰

²⁰ The NPRM (at ¶40) asks whether to require compliance with the RF exposure standard at a distance of 2 cm from the antenna. Two cm could be a difficult distance from which to measure compliance, since most of the available test equipment incorporates a 5 cm standoff between the active probe and any nearby surface.

CONCLUSION

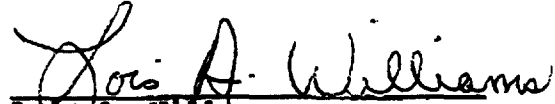
60. The FCC should move promptly to allocate spectrum for use by vehicular collision avoidance radars in order to encourage the introduction of this technology into the marketplace. GM believes that vehicular collision avoidance radars offer the promise of many public benefits, including the potential for improved highway safety. Approving the proposed spectrum allocations will promote the creation of a vigorous competitive market offering a wide variety of different technical approaches. The one allocational aspect that GM believes should be modified is the substitution of 152-154 GHz as a vehicular radar band in lieu of the proposal for 139-140 GHz.

61. GM believes that some modifications in the proposed technical rules would significantly benefit drivers by improving the performance and reducing the cost of vehicular radars. These modifications include allowing higher power, relaxation of the proposed side lobe suppression requirement, reduction of the required out-of-band suppression to 25 dB below the in-band allowed power, explicitly allowing the use of separate transmitter and antenna measurements where feasible, eliminating the need to unnecessarily scan frequencies where no emissions are at all likely, and modification of the proposed 1 km/hr threshold.

62. In view of the significant public interest benefits obtainable from millimeter wave vehicular radars, GM strongly urges the Commission to promptly adopt the

vehicular radar portions of the NPRM with the modifications proposed herein.

Respectfully submitted,



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January 30, 1995

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Technical Appendix A

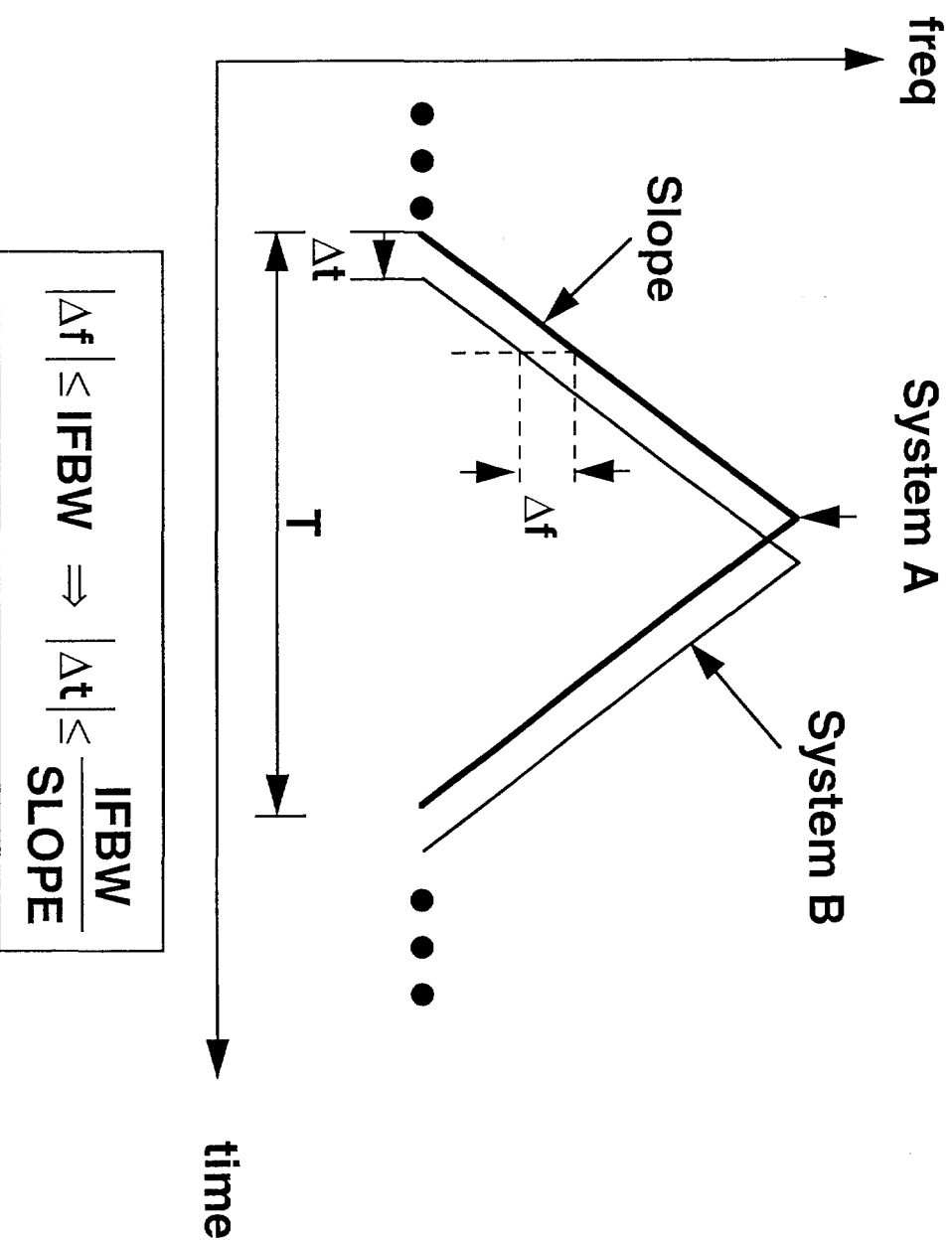
Forward-Looking Radar Interference Analysis: Probability of False Alarms

Like Systems Mutual Interference— First Order Analysis

- ◆ **P_{FA}**: Probability of false alarm due to mutual interference of two like systems
- ◆ **P_{SYN}**: Probability of synchronization of signal transmission of the two like systems
- ◆ **P_{OVLP}**: Probability of the RF frequencies of the two like systems overlapping each other—depends on manufacturing control
- ◆ **P_{ANT}**: Probability two antennas look at each other
- ◆ Since synchronization and RF overlap, and antenna boresighting are caused by independent processes, they are independent. Thus,

$$P_{FA} = P_{SYN} \cdot P_{OVLP} \cdot P_{ANT}$$

Mutual Interference: Synchronization Requirement

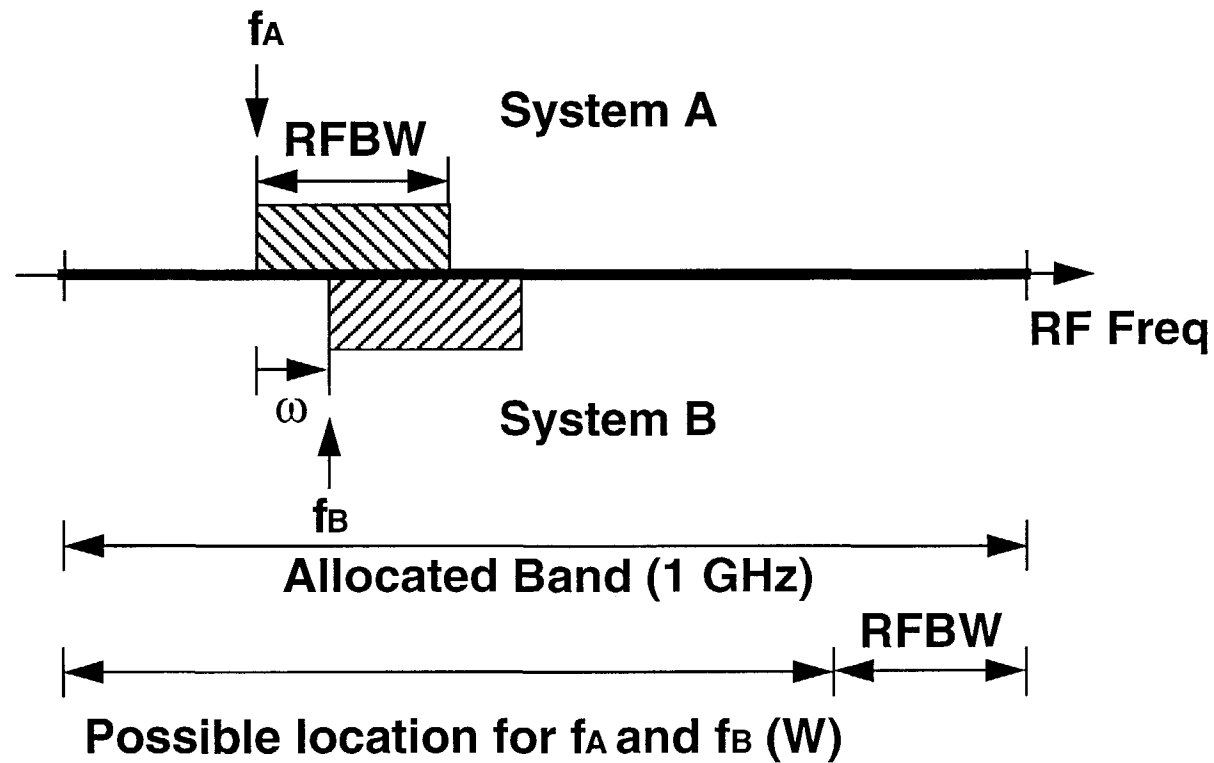


Mutual Interference: Probability of Synchronization

- ◆ Waveform is repeated with period of T
- ◆ Assuming that the two systems have completely random start-up,

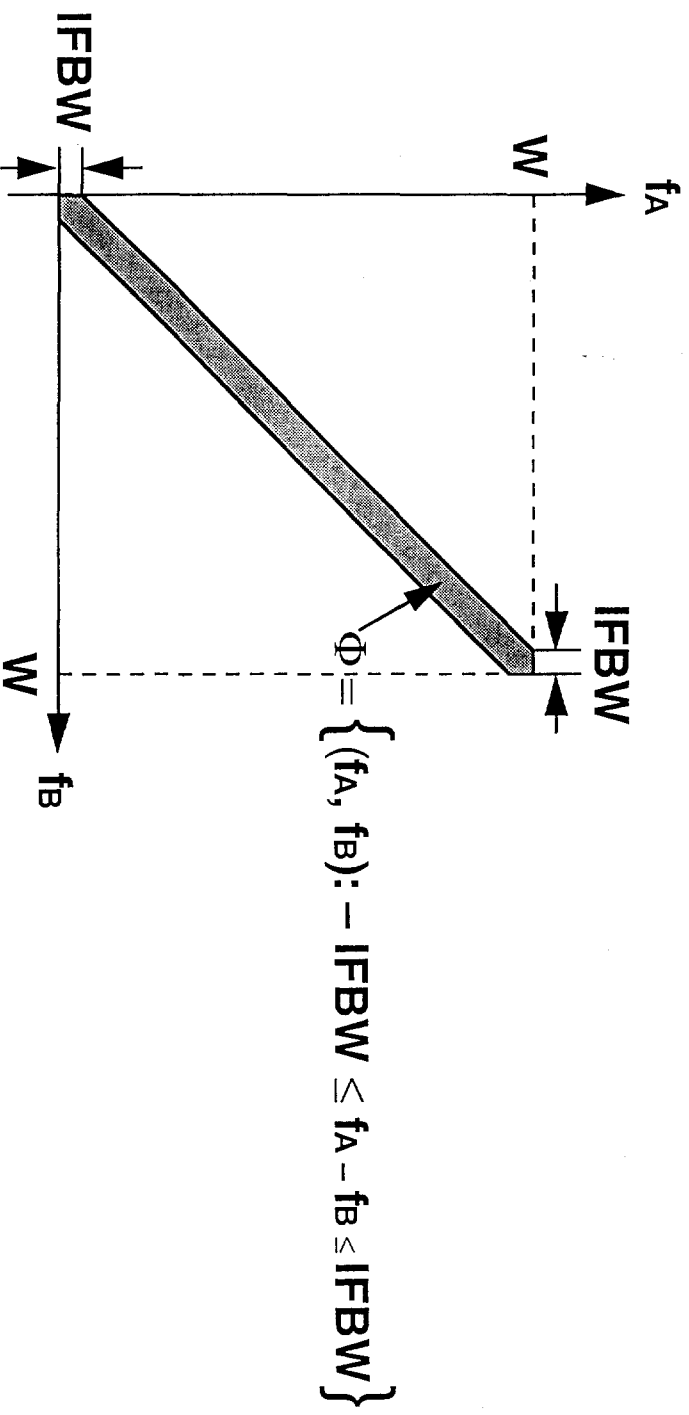
$$P_{\text{SYN}} = 2 \cdot \frac{\left(\frac{\text{IFBW}}{\text{Slope}} \right)}{T}$$

Mutual Interference: RF Overlap Requirement



$$-RFBW \leq \omega \equiv f_B - f_A \leq RFBW$$

Mutual Interference: The Condition for RF Overlap



Mutual Interference: Probability of RF Overlap

- ◆ Assuming that f_A and f_B are uniformly distributed over the $W \times W$ sample space, then

$$P_{OVLP} \approx \frac{2 \cdot IFBW}{W}; \quad IFBW \ll W$$